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## AGRICULTURAL EXPERIMENT STATION.

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### *The Lakes of the San Joaquin Valley.*

The rapid contraction by evaporation of the three lakes of the upper San Joaquin valley, the consequent concentration of their waters into alkaline lyes too strong for animal life, and the nature of the soils laid bare on their margins, have formed the subjects of investigation and discussion in former reports of this department, especially in connection with the reclamation and cultivation of alkali soils. (See reports for 1879, pp. 30 to 39; 1880, pp. 12 to 33; 1882, pp. 56 to 60; 1884, pp. 61 to 69; 1886, revised reprint from report of 1880: "Alkali lands, Irrigation and Drainage in their mutual relations," 45 pp.) It is a matter of regret that it has not been possible to pursue the subject by personal visits as systematically as its practical importance and theoretical interest might have warranted; for we are here in presence of a group of phenomena that have been repeated many times in past geological epochs, and for the study of which, in their physical, chemical and biological aspects, opportunity is not often afforded. Hence, while the information and data here given are of necessity incomplete and fragmentary, they are of interest as affording an insight into processes regarding which but little is thus far on record; and their communication may perhaps serve to incite others having the opportunity to do so, to a closer study of the progressive changes.

For a better understanding of the situation in the Kern and Tulare basins, the following statements from former reports are reprinted:

"A personal examination of Kern lake, and of the region lying between it and Buena Vista lake, as well as of the Mussel Slough country, made under the auspices of the United States census, in March, 1880, satisfied me that in none of these rich agricultural sections could the slightest increase of alkali be safely risked; and analyses subsequently made of the waters of both Kern and Tulare lakes prove that a very few years' use of the water then filling either of these reservoirs would be promptly fatal to the productiveness of the lands irrigated. As regards Kern lake, this was obvious enough from a casual

examination and tasting of the water. Having been shut off from the natural influx of Kern river for a number of years, it has been rapidly evaporating and receding from its former shores, so that at the time of my visit a difference in level of over four feet had been produced in 15 months, leaving high and dry a boat wharf built at that distance of time. About 18 months before, all the fish and turtles in the lake had suddenly died, creating a pestilential atmosphere by their decay; and even the mussels were now mostly dead, a few maintaining a feeble existence. A strong alkaline taste and soapy feeling of the water fully justified their choice of evils. The tule marsh, laid dry by the recession of the lake, was thickly crusted with alkali, and the tules were dead, except where still moistened by the water of the lake, showing that the latter was not yet too strong for such hardy vegetable growth, albeit fatal to animal life.

"Buena Vista lake was stated to be in a similar condition, but not yet quite so far advanced in evaporation, and still maintaining some animal life in its waters, having lost its connection with the river more recently. Tulare lake is well known to be full of fish, and as it annually receives the overflow of Kern and the regular inflow of King's river, its evaporation and recession has been much slower; yet its water's edge is now distant several miles from the former shore-line, and as the water of the rivers is more and more absorbed by irrigation it will doubtless continue to recede until a point is reached at which the regular seepage from the irrigated lands will balance the evaporation. This epoch would seem, however, to be quite in the future as yet, for the rate of recession has, apparently, not sensibly changed in the last few years. It is not likely in any case that the water of the lake will be more abundant or less impregnated with mineral matter than is now the case, at the time when the state of equilibrium shall have been reached.

"With the lights now before us, it can hardly be regretted that the old Westside ditch, which was to irrigate the lower country with the corrosive waters of Tulare lake, was not successful. The lake level is now several feet below the bottom of that outlet, and the lake keeps receding annually, and its alkali becomes stronger as the mass of the water decreases. It is difficult to say where it will stop; but if, as is probable, a state of equilibrium is reached whenever the waters of Kern and King's rivers shall have fully



filled the parched depths of the plains by a more general system of irrigation, it is not at all probable that the lake water will thereby become fresher; on the contrary, such seepage water will be likely to bring into it the alkali now dried up in the lower strata, and the annual evaporation will concentrate the solution more and more. It would certainly be most desirable to utilize the lake as a great reservoir for irrigation supply; but to render this practicable, it would be necessary first to empty out or displace the mass of alkaline water at present occupying the basin. The discussion of the feasibility of such an undertaking, however, belongs to the province of the engineer corps.

"The analyses referred to above gave the following results (in grains per gallon):

	Kern Lake.	Tulare Lake.
	1880.	1889.
Date of taking sample.....	March.	January.
Total solid contents.....	211.50	81.80
Soluble after evaporation.....	182.75	71.16
Potassium sulphate.....		3.24
Sodium chloride (common salt).....	115.41	22.77
Sodium sulphate (Glauber's salt).....		17.23
Sodium carbonate (sal-soda).....	64.37	27.92
Insoluble after evaporation.....	9.29	8.36
Calcium carbonate.....		2.97
Magnesium carbonate.....		4.95
Silica.....		44
Organic matter and water.....	22.43	2.28

"To convey to those unaccustomed to the consideration of such matters an idea of the meaning of the above figures, it may be stated that the solid contents of river waters vary usually from 5 to 12 grains per gallon. The water of Tulare lake, where it is undiluted by the inflow of King's river, is therefore about 10 times, and that of Kern lake about 26 times, stronger than an average river water. Even this, however, conveys but an inadequate idea of the relation sustained by these waters to organic life. The average sea water (containing mainly common salt) is about ten times stronger than the water of Kern lake as regards its solid contents; yet in sea water, fresh-water fish live freely during part of the season, while in Kern lake the fish died at a time when, according to a minimum estimate, the water must have had about twice the strength of Tulare lake, or about one-thirteenth of the strength of sea water. This shows strikingly the deadliness of the Kern lake alkali as compared with sea salt, or, in other words, of Kern lake water as compared with tide water."

#### Condition of the Lake Water in June, 1888.

Early in June, 1888, at my request, Mr. B. F. Moore, Patron of the Experimental Station near Tulare City, sent a messenger to obtain a sample of the lake water in order to ascertain the progress of evaporation. The sample was taken 2½ miles out in the lake, 8 miles east of the mouth of King's river, not far from the Cross creek fisheries.

The water had a general greenish turbidity and considerable greenish sediment at the bottom of the bottles. This sediment showed under the microscope an abundance of green cellular plants, mingled with adherent fine silty matter, partly silicious, partly calcareous.

A partial analysis of this water (by Assistant Geo. E. Colby) resulted as follows:

	Grains per gallon.
Total solid contents.....	204.7
Soluble after evaporation.....	186.9
Sodium carbonate (sal-soda).....	74.3
Insoluble part.....	3.7
Organic matter and water.....	14.1

The soluble part consists chiefly of carbonate

of soda and common salt with some Glauber's salts.

The insoluble part consists of gypsum and carbonates of calcium and magnesium with some silica and alumina (probably clayey matter).

It will be seen from a comparison of this analysis with those made in 1880, that the solid contents of the lake water had increased very nearly 2½ times in the eight years, and that its concentration approximated closely to that of Kern lake in 1880. Yet it appears that an abundance of fish survived, at least of certain kinds, although, as will be seen below, the mussels had already succumbed.

#### The Condition of Tulare Lake in Winter of 1888-9.

Having been informed in November, 1888, that "the fish in Tulare lake were dying by shoals," I concluded that the water of that basin had by evaporation at length reached the limit of endurance of its inhabitants, who had probably found themselves unfit to survive the altered surroundings. Desiring to verify the facts, I in January, 1889, made arrangements to visit the lake in company with Mr. J. G. Woodbury of the State Fish Commission; but being delayed by imperative duties, I requested Mr. Woodbury to proceed alone, and while making his observations on the economic side of the question, to collect a sample of water and such other data as might present themselves. He accordingly visited the northeastern part of the lake, near the mouth of Cross creek, during the first week in February, and on his return communicated to me the following interesting account, which is here reproduced by his consent.

"On the train I met several gentlemen who live along the railroad, opposite the lake, and was told by them that Tulare City was the best place to start from for a visit to the fishing-grounds. I engaged team and driver to take me to the fishery near Cross creek, a distance of about 25 miles, according to the driver's statement, and not less than 20 by my own estimate. At this point the lake receded last year about half a mile, and in consequence the fishermen were compelled to move their position about a mile farther into the lake. Their pound for the fish is half a mile from the shore and their seine is pulled 2½ miles farther out into the lake. It is afterward pulled in by a horse and windlass located about 200 yards from the shore, on a platform where the horse is also stabled.

"They catch about 125 pounds at a haul at this fishery; the fish come in on the seining grounds in warm weather rather than when it is cold; and as the same ground is continually seined over, it seems that the fish must travel considerably to keep it constantly stocked.

"I inquired about the reported dying of the fish. The fishermen said that it occurred last summer and autumn, and that it was mostly catfish, 'greasers' and some of the so-called trout, also some carp, but very few perch. Now it is the perch that is so much valued by the fishermen; in fact, the perch is what they fish for, as the catfish do not sell so well and the greasers are of no account. The 'trout,' of which I did not see any, they say are very soft and do not keep well, also are very insipid.

"The perch is certainly a very fine fish, large,



bright and clean-looking; they are also very good eating, as I had occasion to verify. These perch have enormous mouths, and in that of every one in the pound can be seen a 'shiner,' (or 'slick,' as they call the fish) with the tail sticking out of the great mouth, being drawn farther in as the process of digestion proceeds. One perch which I took along to have cooked, I took by the gills, and looking down his big mouth, I saw the tail of a fish, which I readily got hold of with my fingers and pulled out. It was six inches long and only its head partly digested. The fishermen say that all these perch when caught have fish in their mouths, in proof of which he pulled out one at random with a dip net, and showed the perch with a shiner's tail still out of the mouth.

"The fishermen state that no catfish are now caught, while two and three years ago they would get a wagon-load at each haul; also, that trout are now seldom caught, although they used to be very abundant. The men expressed no opinion as to the cause of the death of the fish, but stated that the catfish especially were drifted upon the shore, dead, by thousands.

"Catfish, however, are found by millions at present in the creeks and sloughs that run into the lake. A gentleman who lives on his farm fully ten miles from the lake, and who fishes in a small way for his own table, is of opinion that the destruction of the catfish and carp is caused by their being driven on the shallows by the wind, and left in shallow pools which, when the water recedes, soon become so hot that the fish die. I questioned him very particularly about this; and as he is very intelligent and his father was a fisherman whom he frequently assisted in his work, his views are entitled to weight. He has a boat and sailed around the lake last summer, and states that the deepest part of the lake, in the channel which runs from south to north in the direction of the old outlet into the San Joaquin river, does not exceed 20 feet; that outside of that channel it is generally not over four feet, gradually shallowing toward the shore. Notwithstanding this shallowness, the action of the wind should mingle the different portions pretty thoroughly and render the alkali about even throughout.

"Before starting on this trip he was told that he would have a good wind throughout his journey, as the wind blew from the center of the lake toward the shore. He states that he found it to be true; that he had the wind 'abeam' all the way.

"The two bottles of water I sent you were taken at various distances from the shore out to the fish-pound. Although the fishery is located off the mouth of Cross creek, as there is no water in that creek for several miles out from the lake, the water of that portion could not have been perceptibly freshened by its influx at this season, although some seepage doubtless occurs. The water of the lake is very muddy and has a nasty taste and smell; very much like that of a well about a mile from shore and 100 feet deep, which was, however, drank by the people at the farmhouse as well as by their stock, and left them all healthy. One of the horses of my team, however, was relaxed in its bowels all the way to Tulare, and the same happened to the driver and to myself.

"All the shore of the lake for miles, as far as I could see, was strewn with mussel or clam-shells; the surface of the ground was white with them, and the wheels of the carriage crushed through them as though more than half the substance of the ground was actually made up of shells, as I have no doubt is really the case. They told me that these shells extend here, as thickly as on top, down to the depth of a hundred feet, as shown in the well referred to above. Not a live clam can be found in the lake now.

"I have subsequently been informed that ten years ago there were large numbers of live mussels in Tulare lake and that the hogs used to live on them then; that they would wade out into the lake and plunge their heads under water, get hold of a mussel and hold their noses up in the air and chew them up.

"All the (seven or eight) fisheries are located within four miles of Cross creek mouth; no fishing is now or appears to have been done near the mouth of King's river, 10 miles to northward, for the reason (according to the fishermen) that the water is too shallow.

"For the whole distance of 20 miles from Tulare City the country is of remarkable fertility, almost level, and where put into wheat the growth was strong, even to within two miles of the shore of the lake, where the land had been plowed through solid tule roots. The growth was very compact, strong, and of a beautiful green color, and had stood out abundantly; which, to my mind, showed that the rawness of the soil or the quantity of alkali had but little effect upon the growth. For long distances among the tules alfalfa covered the ground. I had no idea of the value and extent of the arable land of Tulare county until I rode over the immense extent of that plain to the lake. I think the time will come when Tulare will be one of the very best of the agricultural counties of the State.

"Speaking of the future of the lake—it must have been a good deal lower than it is now, for near the mouth of Cross creek there are many stumps which were under water only last year, and among which the fishermen used to get their nets entangled; these stumps are now just at the water's edge. Of course they could not have grown under water. Again, in a little surface well near the landing-place at the fishery, there is at the depth of about 18 inches, all around, a ring of blackish organic matter or mold, quite distinct from the yellowish clayey earth both above and below it. It looked as if it might be decomposed tules, and if so, the water must have been off the ground long enough to allow these tules to be decomposed and made into soil. There are now under this water about 200,000 acres of land of what might be made the best quality, and this land under alfalfa would be worth many times what it is now under water, for fishes. Why would it not be a good idea to drain this lake down four feet lower, to the banks of that channel, into the San Joaquin river, through a canal that would at the same time serve as a water-way up to that old channel in the lake through which boats could go with freight? I think that by this scheme in a short time all the surplus alkali would be drained into the ocean from the lake and the surrounding country, for as the fresh water from the mountains is spread over



the land it must sink down and gradually push the more alkaline waters down the canal. So the land would in time be freed from alkali and the canal would be kept full by underdrainage, which the lake now receives and evaporates."

#### Present Composition of Tulare Lake Water.

The sample of water sent by Mr. Woodbury was quite turbid, partly from fine mud, partly from the presence of greenish micro-organisms. Its taste was flatfish saline, and quite nauseous to the stomach. Exposed to the light, it soon became filled with rapidly increasing green gelatinous films and cocci, the exact nature of which was not investigated.

Upon filtration, which progressed very slowly, and did not clear the water completely (as is usual with waters impregnated with alkaline carbonates), considerable organic matter still remained in solution, and had to be removed by ignition before proceeding with the analysis. In presence of an excess of carbonate of soda, this ignition could not interfere with the accuracy of the determinations of acidic ingredients.

The result was as follows:

#### Analysis of Lake Tulare Water.\*

Specific gravity, 1.0050 at 62.5°.

	Grain per gallon.	Parts in 10,000.
Total solids.....	303.07	51.88
<i>Soluble after evaporation</i> .....	297.97	47.93
Sodium chloride (common salt).....	95.79	16.40
Sodium sulphate (Glauber's salt).....	73.76	12.63
Sodium carbonate (sal-soda).....	94.74	16.22
Potassium sulphate.....	15.68	2.64
<i>Insoluble after evaporation</i> .....	6.97	1.19
Calcium sulphate (gypsum).....	1.47	.25
Calcium carbonate.....	1.07	.18
Magnesium carbonate.....	2.55	.44
Silica.....	1.87	.32
Organic matter and water.....	16.12	2.76

The following table summarizes the composition of the Tulare lake water at the three different periods:

	1880. Jan'y.	1888. June.	1889. Feb'y.
Date of taking sample.....	81.80	204.7	303.07
Total solid contents.....	71.16	186.9	279.97
<i>Soluble after evaporation</i> .....	22.77		95.79
Sodium chloride (common salt).....	17.23		73.76
Sodium sulphate (Glauber's salt).....	27.92	74.3	94.74
Sodium carbonate (sal-soda).....	3.24		15.68
Potassium sulphate.....	8.36	3.7	6.97
<i>Insoluble after evaporation</i> .....			1.47
Calcium sulphate (gypsum).....	2.97		1.07
Calcium carbonate.....	4.95		2.55
Magnesium carbonate.....	.44		1.87
Silica.....	2.28	14.1	16.12
Organic matter and water.....			

The figures in the above table hardly require

\*Analysis by Mr. E. M. Hilgard, Special Student in the Agricultural Laboratory.

comment unless it is to draw attention to the extremely rapid increase of the solid contents of the water between June, 1888, and February, 1889, as compared with the effect produced during the previous 7½ years. The latter was about 2½ times or 150 per cent on the whole, or an average of 13 per cent a year; while in the eight months preceding the last examination, the increase was nearly 45 per cent. It should be noted that these eight months were remarkable for very great evaporation elsewhere on the coast, also; and that they formed the end of three years of rather deficient rainfall in the State. The more abundant moisture of the season just passed, may have stopped or perhaps even reversed the process; a point which will receive attention within a short time. It will then be possible to predict with some degree of approximation how nearly the condition of natural equilibrium between the evaporation from the lake surface and the seepage from the streams and irrigated plains referred to above, is being approached, and to forecast the future of the lake and of its inhabitants if left to themselves.

Whether or not it will be expedient to interfere with the natural course of events, either for the establishment of a great irrigation reservoir, or (as suggested by Mr. Woodbury) for the reduction of the lake to a mere waterway in order to reclaim the land's now covered by it, is a question too complex to be discussed here. The answer will in a measure be determined by the decision of another question, viz.: whether the increased saline strength of the lake water is due wholly to evaporation, or in part to concentrated solutions of alkali extracted from underlying beds by the inward seepage. If a consideration of the area and depth lost by the lake within the last year shall show that there has been a distinct accession of alkali salts from the outside, the use of the drained lake-bed as an irrigation reservoir will be of very doubtful practicability, as it would imply an annual addition of such salts to those already contained in the natural soils irrigated therewith.

It is hoped that all persons who may, from their own observation, be able to throw light upon the history of the recession of these lakes, will communicate the facts so as to place them on record. It is with the hope of obtaining such additional data that this bulletin is issued in advance of the general report of which its subject-matter will form a part.

E. W. HILGARD.

Berkeley, Cal., June 15, 1889.